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Rep. #9

Effect of Sample Size and Environmental Conditions on Evaporation of Water From Soil

Conservation Research Report No. 9



Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Colorado Agricultural Experiment Station

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Effect of Sample Size and Environmental Conditions on Evaporation of Water From Soil

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INTRODUCTION

To achieve proper control of environmental conditions for evaporation studies it has been necessary to use containers of soil in the laboratory. A survey of the literature has shown that many kinds and sizes of containers have been used, the sizes ranging from about 6 cm. in diameter by 122 cm. deep¹ to 32 cm. in diameter by 27 cm. deep.² No indication has been given of the effect that the variations in size of these containers may have had on the results obtained from evaporation studies or whether one experi-

ment could be compared with another with any validity.

This study presents data of water evaporation from soil in which different depths and diameters of sample containers were used with various environmental conditions, including a hexadecanol surface treatment, with the purpose of assessing the relative effects of the containers used. In addition, data are presented to examine the effects of external and internal environmental factors on the evaporation of soil water.

PROCEDURE

Soil water evaporation rate was measured for soil in containers of various diameters and heights. The container diameters were either 4.0, 10.5, or 16 cm., and the container heights were 7.6, 15.2, 24.0, or 30.5 cm. Several combinations of diameter and height were tested. Table 1 gives the combina-

tions for the various runs. In addition, evaporation from a soil with a surface treatment of hexadecanol was compared with the untreated soil and with evaporation from a free-water surface. There were three replications of each soil treatment with one replication of free-water containers for each run. The hexadecanol treatment was included in all runs except the final run with Loveland soil. The containers were placed on graduated blocks so that the heights of all were equal.

Two soils were used for separate tests, Fort Collins clay loam and Loveland fine sandy loam. The

¹ BUCKINGHAM, L. E. STUDIES ON THE MOVEMENT OF SOIL MOISTURE. U. S. Bur. Soils Bul. 38, 61 pp. 1907.

² COLLIS-GEORGE, N., HENIN, S., and KELLY, J. A. ETUDE DU MECANISME DE LA DESSICCATION DES SOLS PAR EVAPORATION. [Paris] Acad. des Sci. Compt. Rend. 257: 242-244. 1963.

clay loam was more subject to swelling and shrinking with changes in water content than was the sandy loam. The soils were prepared by passing them through a 2.5-mm. sieve and allowing them to air dry. The containers were packed as uniformly as possible with the use of a tremie. The bulk densities achieved were 1.25 g./cc. for the clay loam and 1.32 g./cc. for the fine sandy loam. The hexadecanol treatment was applied by mixing powdered hexadecanol with the top 0.6 cm. of soil at a rate of 0.126 g./cm.² or 5.6 tons per acre.

The water was applied to the containers through layers of cheesecloth to reduce puddling of the soil surface. The containers were then covered and allowed to equilibrate for 2 days before the evaporation process was started. They were

then placed on 6- and 7-foot circles on a turntable that rotated at 2 r.p.m. Two check and two surface-treated replications were on the outer circle. The remaining replicates of each treatment and the replicate of water alone were placed on the inner circle. Weights were taken daily to determine water loss. The soil columns were allowed to dry without further addition of water, but the water columns were refilled daily after weighing. At the completion of each run the soil was rewet to the desired moisture content, covered, and let stand for 2 days before starting the next run.

This report presents only a part of the data available because of similarity of results. Partial data from six experiments are presented (table 1). These are from two

TABLE 1.—*Basic data of tests for evaporation studies of uncovered (untreated) and surface-treated (with hexadecanol) soil, Fort Collins, Colo.*

Soil and test	Initial soil water content by volume	Containers	
		Diameters	Depth
Fort Collins clay loam:	<i>Percent</i>	<i>Centimeters</i>	<i>Centimeters</i>
Run 1, greenhouse ¹ -----	43.8	4.0, 10.5, and 16	7.6, 15.2, 24.0, and 30.5
Run 2, greenhouse ¹ -----	³ 31.2	4.0, 10.5, and 16	7.6, 15.2, 24.0, and 30.5
Run 3, constant temperature ² --	37.5	4.0, 10.5, and 16	15.2, 24.0, and 30.5
Loveland fine sandy loam:			
Run 1, constant temperature, ² without radiation -----	46.2	4.0, 10.5, and 16	7.6, 15.2, 24.0, and 30.5
Run 2, constant temperature, ² with radiation -----	³ 39.6	4.0, 10.5, and 16	7.6, 15.2, 24.0, and 30.5
Run 3, constant temperature, ² without radiation -----	³ 39.6	10.5	15.2, 24.0, and 30.5
Run 4, constant temperature, ² with radiation ⁴ -----	33.0	10.5	30, 45, and 60

¹ Greenhouse temperature 15° to 30° C., relative humidity of 50 to 85 percent.

² Room with temperature of 23° ± 1° C., relative humidity of 40 to 50 percent.

³ Soil of run 1 rewetted.

⁴ Check only.

runs with Fort Collins clay loam under greenhouse conditions and one under constant temperature with no added radiation; four runs with Loveland sandy loam under constant temperature, two of these

with radiation added, and two without. All constant temperature tests were at $23^{\circ} \pm 1^{\circ}$ C. and the radiation was supplied by infrared heat lamps placed 50 cm. above the tops of the containers.

RESULTS

In the first run, Fort Collins clay loam was used in the greenhouse. The water content was 43.8 percent by volume. The data for the first run are plotted as cumulative evaporation versus time in figure 1.

The data show that the cumulative evaporation increased as sample depth increased. The cumula-

tive evaporation for the hexadecanol-treated soil was less than for the untreated soil at all depths during the experiment. The difference in cumulative evaporation between the treated soil and untreated soil increased to a maximum and then decreased. A maxi-

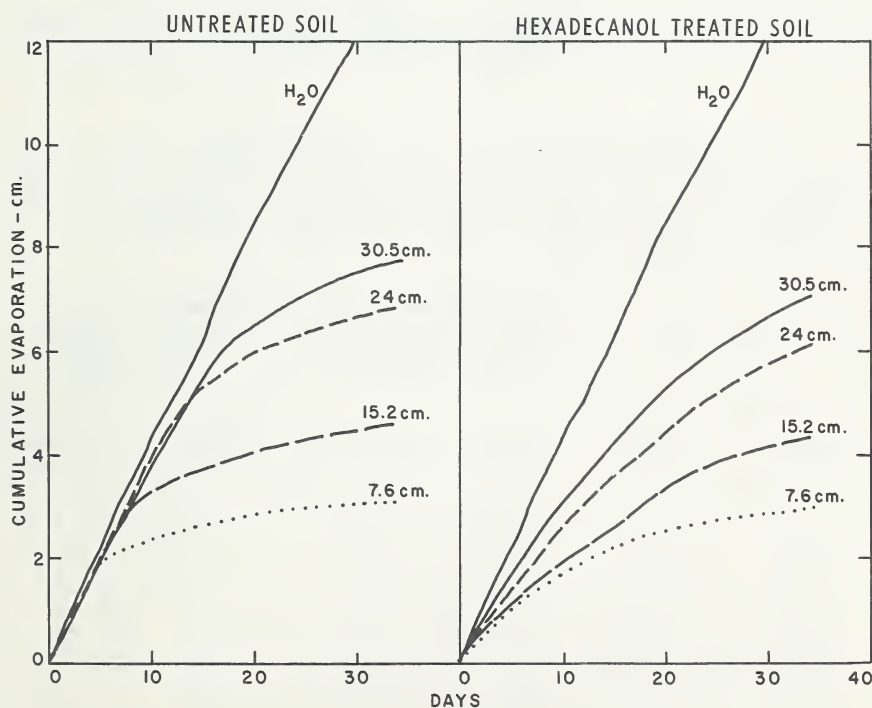


FIGURE 1.—Cumulative evaporation for Fort Collins clay loam in containers 16 cm. in diameter and various depths; greenhouse run with initial soil water content of 43.8 percent by volume.

imum difference occurred because the evaporation rate for the untreated soil eventually decreased more rapidly than did that for the hexadecanol soil. The maximum differences are shown in table 2 for all heights and diameters. The differences generally decreased with decreasing depth of soil.

The cumulative evaporation curves for containers of the same height (30.5 cm.) but with various diameters are shown in figure 2. There were no significant differences between cumulative evaporation for various diameters over the total time studied. However, there was an increase in evaporation rate with a decrease in sample diameter during the constant rate portion of the evaporation curve.

The second run of Fort Collins soil was similar to the first run but with a lower initial water content

(31.2 percent by volume). Figure 3 shows the cumulative evaporation versus time comparison for the 16-cm.-diameter by 30.5-cm.-deep columns for the two runs. The major difference between the cumulative evaporation curves for the two runs is the lengthened linear part of the curves for those columns with higher initial water content. This magnifies any differences between treatments that occurred at that time.

The final run to be reported for the Fort Collins soil was run in the constant temperature room without heat lamps. The temperature was $23^{\circ} \pm 1^{\circ}$ C. with a relative humidity of 40 to 50 percent. The soil was removed, air-dried, sieved, and repacked to the same bulk density as the previous runs. The columns were wet to 37.5 percent water. The 7.6-cm. depth was ex-

TABLE 2.—*The influence of sample height and diameter on the maximum difference (MD) in cumulative evaporation due to surface treatment. Greenhouse tests with Fort Collins clay loam. The initial water content (θ) = 0.438 by volume*

Container size		Average moisture content (θ) at time of maximum difference in cumulative evaporation for—		Maximum difference in cumulative evaporation between treated and untreated soil	
Height (cm.)	Diameter (cm.)	Untreated soil	Hexadecanol-treated soil	In centimeters of water	Time when it occurs
		Percent	Percent		Days
30.5	16	18.6	24.5	1.42	17
24.0	16	15.9	29.1	1.78	15
15.2	16	17.1	29.0	1.44	9
7.6	16	11.5	26.4	.70	5
30.5	10.5	17.2	23.6	1.56	16
24.0	10.5	18.0	25.2	1.40	11
15.2	10.5	17.1	26.4	1.14	7
7.6	10.5	12.4	25.4	.79	5
30.5	4	20.9	31.1	2.57	10
24.0	4	21.6	32.0	2.01	6
15.2	4	19.4	32.1	1.56	4
7.6	4	--	--	--	--

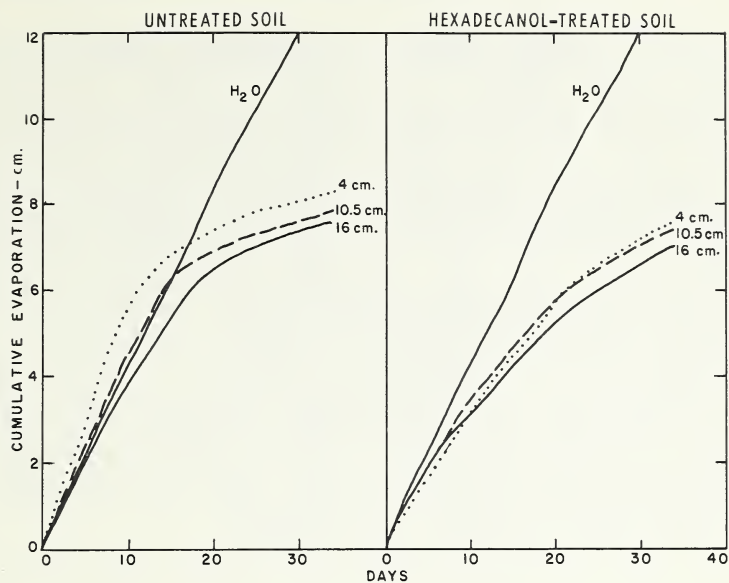


FIGURE 2.—Cumulative evaporation for Fort Collins clay loam in containers 30.5 cm. deep and various diameters; greenhouse run with initial soil water content of 43.8 percent by volume.

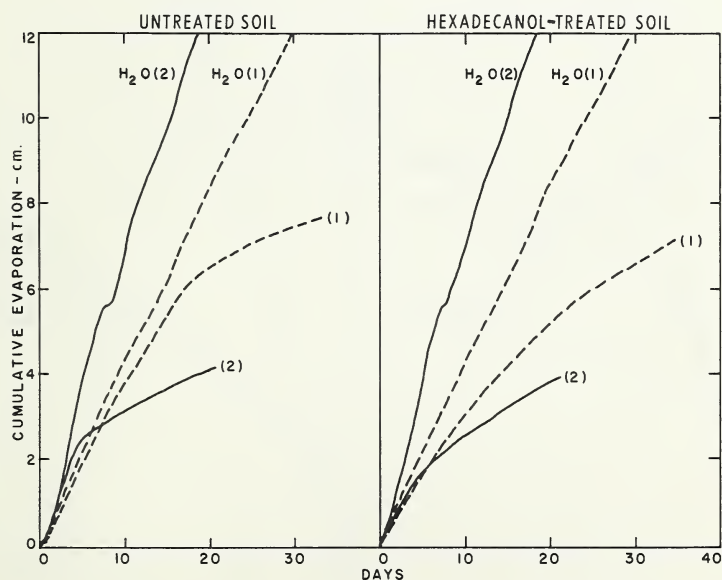


FIGURE 3.—Comparison of cumulative evaporation from Fort Collins clay loam at initial soil moisture contents of 43.8 and 31.2 percent in containers 16 cm. in diameter and 30.5 cm. deep; greenhouse runs 1 and 2.

cluded from this study. Cumulative evaporation is plotted as a function of time in figure 4 for three depths for 16-cm.-diameter containers. The results are very similar to those run in the greenhouse except for the increased slope and length of the constant rate portion of the curve.

Three runs were made with the Loveland fine sandy loam and the same physical setup as for Fort Collins clay loam in the previous series. All these runs were in the constant temperature room. The first run with newly packed soil (bulk density of 1.32 g./cc.) had no added radiation and a water content of 46.2 percent by volume.

Cumulative evaporation versus time for all depths for 16-cm.-diameter containers is given in figure 5. The general features of the curves are similar to those for Fort Collins clay loam in figure 1. Total cumulative evaporation increased when the soil columns were longer. Curves comparing the evaporation versus time for the 30.5-cm. depth, grouped by diameters, are shown in figure 6. There was no consistent difference in the total amount evaporated in containers with different diameters, but evaporation rates were higher in the smaller diameter soil columns during the time when the rates were not changing.

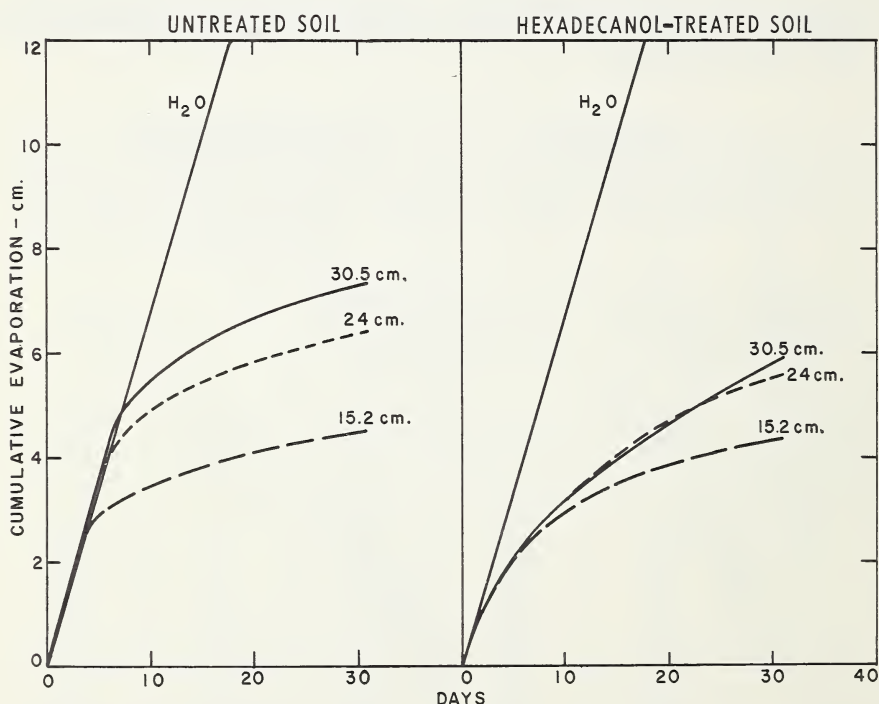


FIGURE 4.—Cumulative evaporation for Fort Collins clay loam in containers 16 cm. in diameter and various depths; constant temperatures at 23° C. and no added radiation, with initial soil water content of 37.5 percent by volume.

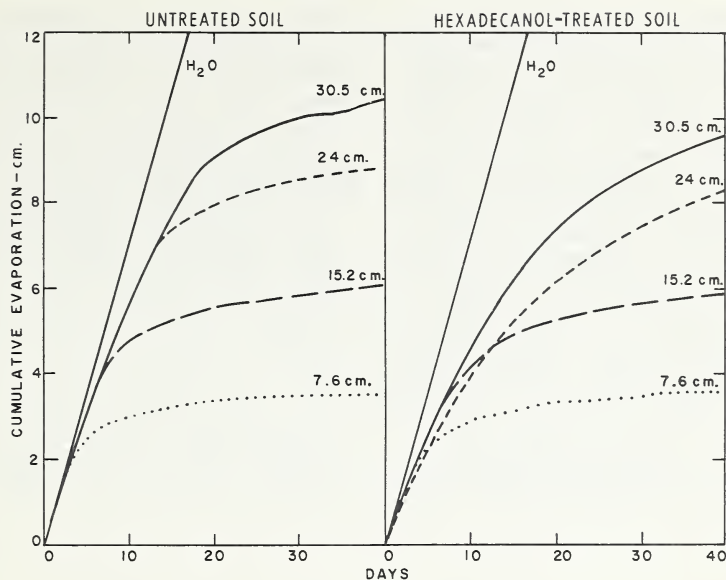


FIGURE 5.—Cumulative evaporation for Loveland fine sandy loam in containers 16 cm. in diameter and various depths; constant temperature and no added radiation, with initial soil water content of 46.2 percent by volume.

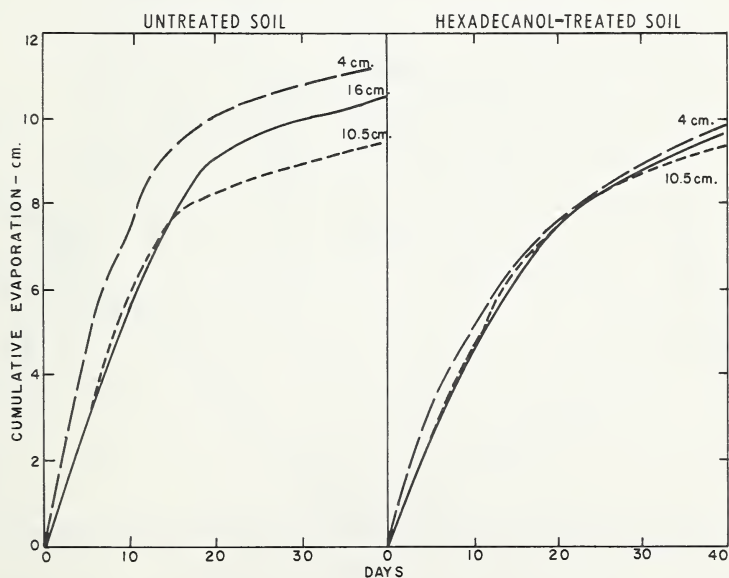


FIGURE 6.—Cumulative evaporation for Loveland fine sandy loam in containers 30.5 cm. deep and various diameters; constant temperature and no added radiation, with initial soil water content of 46.2 percent by volume.

The second run of Loveland soil was similar to the first except that the soil was rewetted to 39.6 percent by volume without repacking and the surfaces received radiation. The data for 16-cm.-diameter containers are presented in figure 7. Rate of evaporation during the time when evaporation rate was constant was greater under the radiation treatment than under the no-radiation treatment (fig. 5). The hexadecanol treatment without radiation had a slight reduction in evaporation rates compared to the check soil during the time when evaporation rate was constant, but the hexadecanol-treated soils with radiation had a rather

sharp change in slope after about 1 or 2 days, with a much greater difference when compared to the check. The curve then stayed on a constant slope for some time, which indicates the presence of a constant barrier to evaporation.

Because there was some question whether the above differences were due to radiation differences or to some soil difference caused by wetting and drying, another nonradiated run was made with the same soils. The third run was a rerun of only the 10.5-cm.-diameter containers but with the 7.6-cm. depth excluded. The water content was 39.6 percent by volume. The data

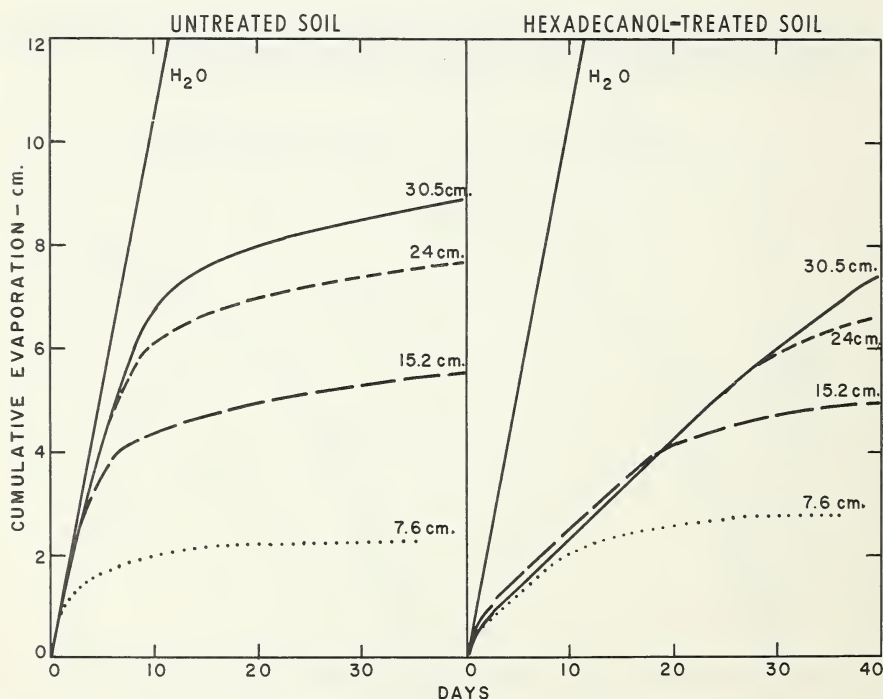


FIGURE 7.—Cumulative evaporation for Loveland fine sandy loam in containers of 16 cm. in diameter and various depths; constant temperature and with added radiation, with initial soil water content of 39.6 percent by volume.

for cumulative evaporation are shown in figure 8. The curves are similar to those for the same soil with radiation but with reduced slopes for the constant rate portion of the curves. Considerable difference in soil characteristics resulted from wetting and drying in the hexadecanol-treated soils.

One final series involved evaporation from duplicate 10.5-cm.-diameter by 30-, 45-, or 60-cm.-deep columns of Loveland soil under radiation. Only a check treatment was used in this series. The cumulative evaporation versus time is shown in figure 9. The difference in cumulative evaporation between these curves after the constant por-

tion has ended is very much less than the differences between the curves for the shorter containers. After 90 days of evaporation, the 60-cm. column had lost 8.7 cm. water; the 45-cm. column, 8.4 cm.; and the 30-cm. column, 7.2 cm.

The cumulative evaporation curves show that the length of time that the evaporation rate was constant ranged from about 1 day for the 7.5-cm. depth soil to 10 days for the 30.5-cm. depth of checks for both soils. Figure 7 is representative of the several figures that have the same general features.

A comparison of the curves for the various depths shows a similarity in shape beyond the constant

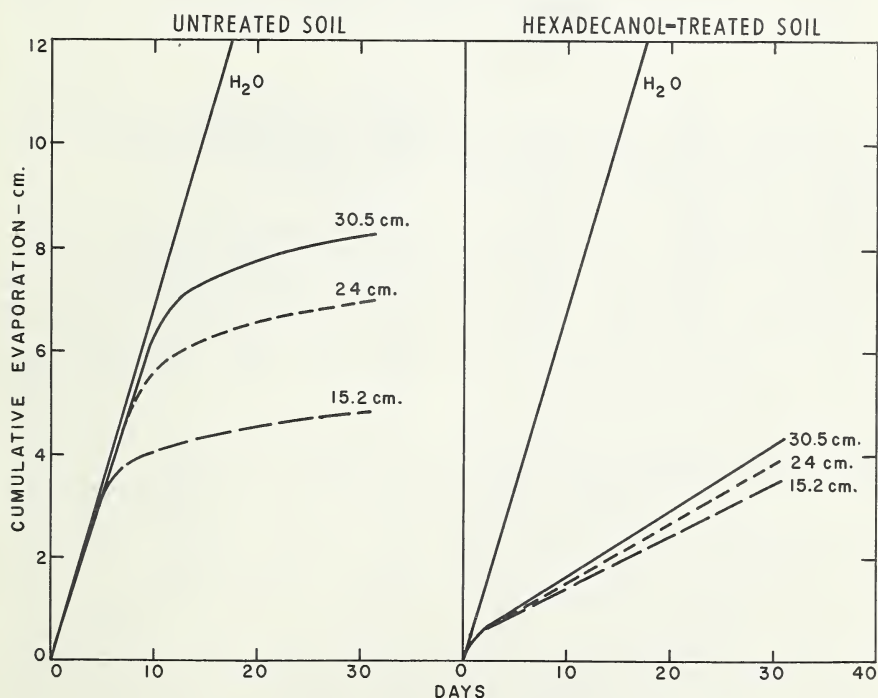


FIGURE 8.—Cumulative evaporation for Loveland fine sandy loam in containers 10.5 cm. in diameter and various depths; constant temperature and no added radiation, with initial soil water content of 39.6 percent by volume.

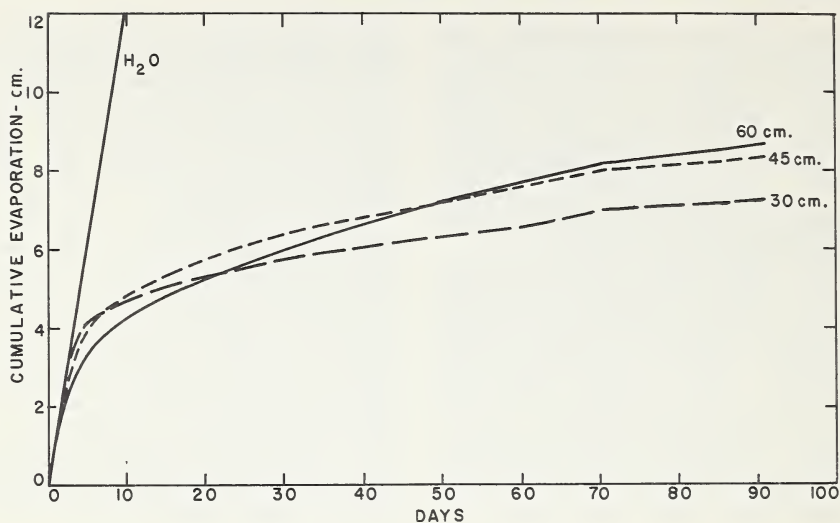


FIGURE 9.—Cumulative evaporation for Loveland fine sandy loam in containers 10.5 cm. in diameter and various depths; constant temperature with added radiation, with initial soil water content of 33.0 percent by volume.

rate portion until about the 20th day. At this time, the 7.6-cm. container had lost most of its water, which caused the evaporation essentially to cease.

A comparison of cumulative evaporation for 30.5-cm. and 7.6-cm. depth columns for untreated and hexadecanol-treated soils is shown in figure 10. This was for Loveland soil, first run without radiation. There was very little difference between the curves for treated and untreated soil with a shallow depth (no greater difference than the expected variation between samples); but for the deep soil, the difference was sufficient to make the treatment effect obvious. The data in figure 9 show, however, that a column 30 cm. deep would probably be sufficient for most tests. A large amount of hexadecanol was applied to the soil to obtain a considerable reduction of evaporation; any lesser reduc-

tion of evaporation would have been missed entirely with the shallow containers.

Although table 3 is concerned only with data from the Loveland check soil with added radiation, the data on the influence of container diameter on cumulative evaporation are similar to those for the other soil and conditions. Table 4 shows the ratio of evaporation rates for the Loveland soil and for the water containers with and without radiation. These ratios are based on the evaporation from the 16-cm.-diameter container with 30.5-cm. depth. The 4-cm.-diameter containers showed a considerable increase in evaporation rate over that of the 16-cm. containers, both with and without added radiation. This also held true for the water containers, but to a lesser extent.

The evaporation rates versus mean volumetric water contents

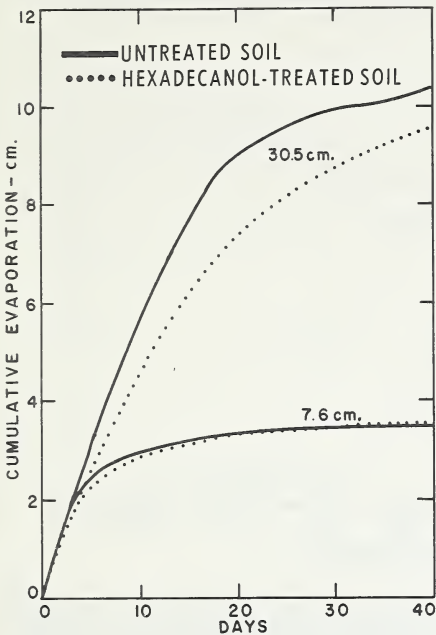


FIGURE 10.—Comparison of cumulative evaporation of untreated and hexadecanol-treated Loveland fine sandy loam in containers 16 cm. in diameter and 7.6 and 30.5 cm. in depth.

with added radiation for the smaller containers approached the same values as for the 16-cm. diameter containers (fig. 11).

A comparison of evaporation rates under the influence of addi-

tional radiant energy with those without radiation also shows the reduction effect of external conditions with the passing of the constant evaporation rate phase (fig. 12).

Figure 13 shows that the evaporation rate dropped off rapidly at a higher water content for the first cycle than it did for the third. This indicated a better continuity of pores, or at least a better transport of water to the surface of the soil after rewetting and drying than with the original soil structure.

TABLE 3.—Cumulative evaporation after 41 days, Loveland soil with radiation

Depth (cm.)	Diameter	CE
	Cm.	Cm. H ₂ O
30.5	16.0	8.90
30.5	10.5	8.65
30.5	4.0	9.20
24.0	16.0	7.75
24.0	10.5	7.48
24.0	4.0	7.45
15.2	16.0	5.57
15.2	10.5	5.19
15.2	4.0	5.43
7.6	16.0	2.30
7.6	10.5	2.97
7.6	4.0	3.10

TABLE 4.—Ratios of evaporation rates, during the initial constant rate period based on the 16-cm. diameter 30.5-cm.-deep containers for Loveland soil and water containers runs 1 and 2

Can diameter (cm.)	Evaporation ratio			
	Soil		Water	
	No radiation	Radiation	No radiation	Radiation
4.0	1.62	1.42	1.28	1.05
10.5	1.20	1.05	.99	.99
16.0	1.00	1.00	1.00	1.00

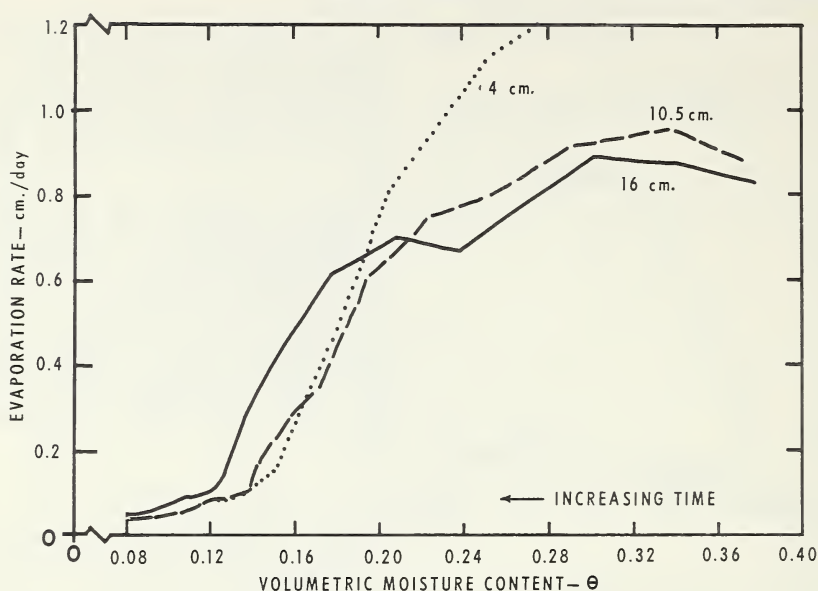


FIGURE 11.—Evaporation rate versus mean volumetric water content for Loveland fine sandy loam in containers 24 cm. deep and various diameters; constant temperature and with added radiation, with initial soil water content of 39.6 percent by volume.

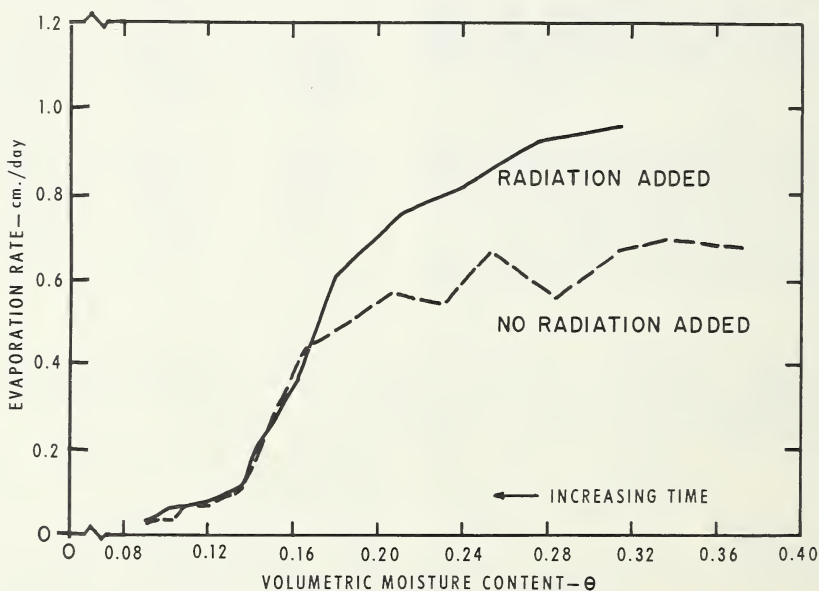


FIGURE 12.—Evaporation rate versus mean volumetric water content for Loveland fine sandy loam in containers 24 cm. deep and 10.5 cm. in diameter; constant temperature with and without radiation, with initial soil water content of 39.6 percent by volume.

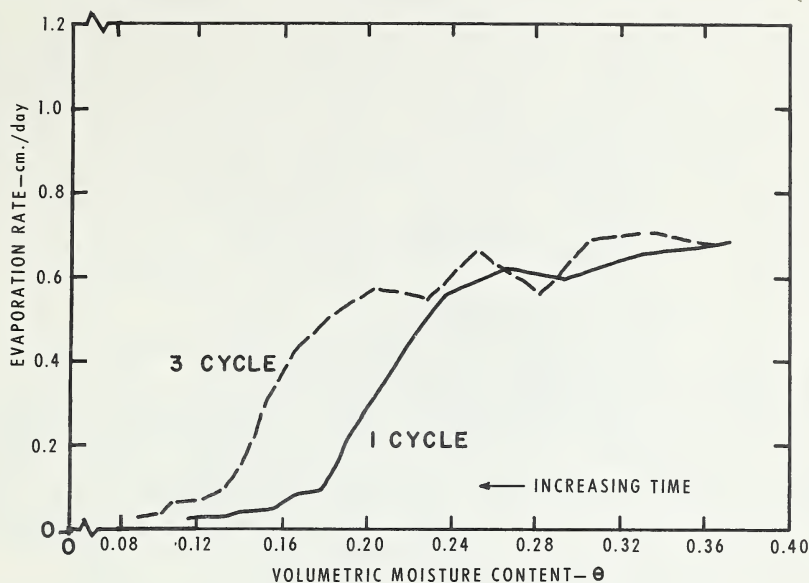


FIGURE 13.—Evaporation rate versus mean volumetric water content of one and three cycles for Loveland fine sandy loam in containers 24 cm. deep and 10.5 cm. in diameter; constant temperature and without added radiation, the soils were wet and dried through three cycles, with initial soil water content of 46.2 percent by volume.

DISCUSSION AND CONCLUSIONS

Generally speaking, the shallower the container, the shorter the constant rate portion of the curve. In addition, the total length of time that a test may be carried on is limited by the depth of the container, since the total water supply will eventually become depleted. With a shallow container and an initial water content near field capacity, the constant rate phase could be easily missed. The length of time that the constant rate of evaporation would persist would partially depend on the initial water content.

A comparison of the influence of container diameter on cumulative evaporation shows no consistent relationship (table 2). However, there is a considerable difference

in the evaporation rates for the containers of different diameters if only the constant rate portion of the cumulative evaporation curve is considered.

The evaporation rate for the nonradiated cases, compared to those with radiation, have the greatest increase with a decrease in container diameter. This is probably because the advective component of the total energy transfer was greater for the nonradiated case than for the added radiation treatment.

When the evaporation rate from a soil column decreases, the rate of supply of water to the soil surface had fallen below the evaporative demand. Thus, the internal environmental factors should begin to

affect the evaporation rate, provided the potential evaporation rate is greater than the actual evaporation rate. The evaporation rate from a small-diameter container should approach the same value as that from a large-diameter container some time after the constant-rate phase of evaporation has been passed.

When the evaporation rate curve for the Loveland soil without radiation for the first evaporation run was compared to the curve for the third evaporation run, a difference in the curves was noted (fig. 13). This apparently was caused by the slight settling due to the rewetting and drying. There may have been a structural change at the soil surface which changed the soil water conductivity.

Any test involving evaporation of water from soil, or transfer of heat energy from a container of soil, is subject to criticism, since the oasis effect produces an effect even on large fields. However, the present study can be of use if care is taken in the interpretation of data.

The consideration of container diameter and its effect on evaporation rates of water from soil indicates that 10 cm. probably ought

to be the minimum for use in experiments of this kind. The 4-cm. containers of soil had a very much greater evaporation rate than did the 4-cm. containers of water, whereas the larger diameter soil columns tested allowed evaporation rates similar to those from water containers.

Radiant energy applied to the surface reduced the relative contribution of advective energy to the total energy exchange, thereby reducing the effect of diameter.

It is recommended that container height be at least 24 cm. Results with containers shorter than 24 cm. indicated that these could be used only for experiments which would be affected little by the length of the column, such as for studies concerning only the constant rate portion of the cumulative evaporation curve. Containers as short as 7 cm. were of little use.

The wetting and drying history changes the soil water conductivity and, consequently, affects evaporation rates. Since the biggest change occurs during the first wetting and drying cycle, it is recommended that all samples be wetted and dried at least once before the evaporation data are taken.

